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# THROUGHPUT ANALYSIS OF COOPERATIVE SPECTRUM SENSING FOR COGNITIVE RADIO NETWORK

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***ABSTRACT***

***In Cognitive Radio (CR) network, spectrum sensing is a fundamental issue for proper utilization of bandwidth extraction. In earlier researches cooperation among cognitive nodes is used to improve the performance in terms of the detection probability. However it increases the overheads in terms of bandwidth and time required for reporting their decisions to fusion centre whereas these overheads reduces throughput in turn. In this paper, we have investigated the effect of cooperation on throughput when fusion rule is OR. Performance of Cooperative spectrum sensing is investigated in terms of probability of detection and false alarm. Variation in throughput is analyzed with number of users for different value of SNR and time required for reporting the decision to fusion centre called reporting delay.***

***KEYWORDS: Cognitive Radio, Spectrum Sensing, Primary User, Secondary User***

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**Original Article**

## 1. INTRODUCTION

In last few years, rapid growth of wireless applications has increased the demand for radio spectrum. In the traditional approach of spectrum allocation, spectrum is assigned particularly to primary users to operate in a certain specific band. Till now most of the useful spectrum is still occupied or licensed. Even license-exempt has also become over crowded. So the need is to find vacant frequency slots. On the other hand, a FCC report shows that a large portion of the assigned frequency spectrum is not being utilized properly [1]. This inefficient use of most scarce resource like radio spectrum needs a new paradigm for the flexible use of available bands. Cognitive radio is a unique technology for efficient utilization of frequency spectrum. The main motive of the cognitive radio is to sense the frequency spectrum and to detect the presence or absence of the main user. It can use the spectrum only if communication does not interfere with any main user [2]. These secondary users are lower priority users which further ensure the non-interfering co-existence with the main users. However, performance of spectrum sensing techniques are limited by various factors like noise uncertainty, multipath fading, shadowing and hidden node problems [3,4].Cooperative Spectrum sensing is proposed as a solution to overcome these problems [5-8]. In this technique, sensing information available at different locations are used collectively for determining the decision of spectrum availability, thus provides the diversity gain and improves accuracy [9-11]. However, in order to apply cognitive spectrum sensing, local sensing data have to be reported to the fusion center through bandwidth-limited common control channel. This adds the reporting delay to cognitive radio networks (CRNs). To address this issue, the study in [12] proposed that cooperative secondary user sent local sensing data concurrently.

But this scheme will increase the system design complexity or cost. Therefore, given a bandwidth-limited common control channel, the conventional scheme that cooperative SUs report their local sensing data to the fusion center sequentially may be more desirable [13].

In this paper, we evaluate the performance of cooperative spectrum sensing in which secondary user report the local sensing data to the fusion center sequentially. Performance is investigated in terms of Pm, Pf and throughput. The throughput at different number of cognitive radio users in cooperation has been investigated. The rest of the paper is organized as follows. In Section II, the system model is introduced. In Section III, optimal number of users in cognitive radio and throughput of the network have been discussed. In Section IV, results and discussions are presented. Finally Section V presents the conclusions.

## 2. SYSTEM MODEL

This work focuses on detection of a primary signal embedded in AWGN noise and cooperation between individual users. We consider a cognitive network using one primary user, N cognitive users and one fusion centre. Each cognitive user sends one bit local decision $u_1, u_2, ... u_n$ to fusion centre through a common control channel. For local detection, energy detection is used. The decisions from CRs are fused at FC and the final decision is made on the basis of OR fusion rule. In OR rule, if a single CR observe the presence of PU, the FC will take decision in favour of the presence of PU which in turn results in less interference to PU receiver.

We further assume that y (n) is a received vector of length N that consists of signal plus noise. x(n) is the transmitted signal of the primary user, h(n) is the impulse response of channel and w(n) is additive white Gaussian noise with variance $\sigma^2$.Then for detecting a primary user signal, secondary user needs to discriminate between the following two hypotheses:

$$H_0 : y(n) = w(n) \quad (1)$$

$$H_1 : y(n) = x(n)h(n) + w(n) \quad (2)$$

$H_0$ is the null hypothesis which indicates that primary user does not communicate and $H_1$ is the alternative hypothesis that indicates the existence of the primary user.

Energy detector measures the energy of the received waveform over a specified observation time. The test statistic

T ( yi ) for the energy detector is given by [6]

$$E = \sum_{n=0}^{N} |y(n)|^2 \quad (3)$$

Where N is no of samples

Probability of detection PD and Probability of false alarm $P_{FA}$ given as follows:

$$P_d = Pr\,(E > \lambda | H_1) = Q_m\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \quad (4)$$

$$P_{FA} = Pr\,(E > \lambda | H_0) = \frac{\Gamma(m, \lambda/2)}{\Gamma(m)} \quad (5)$$

Where $\gamma$ is the SNR. Γ(.) and Γ(.,.) are complete and incomplete gamma functions , $Q_m$ is the generalized Marcum Q-function and $m = N/2$ where $N$ is degree of freedom.

In this work, we are considering the realistic scenario of imperfect reporting channel. We assume that reporting channels are imperfect binary symmetric with error probability of q. The block diagram of the proposed system is represented in Figure 1.

Then

$$P_{d,q} = [P_d(1-q) + q(1-P_d)] \tag{6}$$

$$P_{f,q} = [P_f(1-q) + q(1-P_f)] \tag{7}$$

Assuming uncorrelated decision, probability of detection [14] for decision fusion using OR is given by

$$P_{d,OR} = 1 - [(1-P_d)(1-q) + qP_d]^K \tag{8}$$

$$P_{f,OR} = 1 - [(1-P_f)(1-q) + qP_f]^K \tag{9}$$

We can also calculate Probability of miss detection as follows:

$$P_{m,OR} = 1 - P_{d,OR} \tag{10}$$

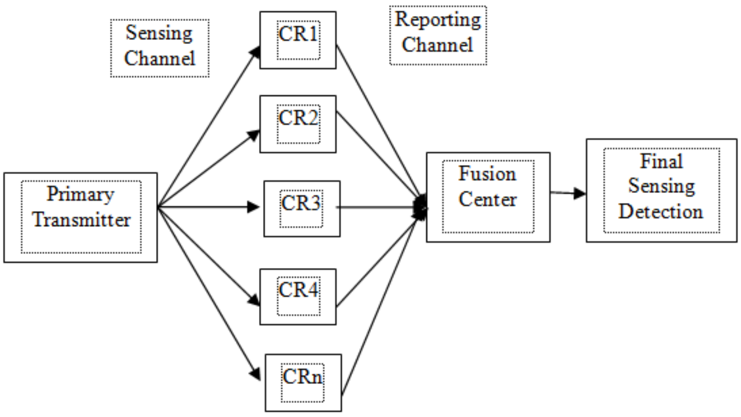


**Figure 1: Block Diagram of the System**

## 3. ANALYSIS OF THROUGHPUT IN COOPERATION

Performance of cooperative sensing is measured by Probability of detection and Probability of false alarm. Probability of detection for cooperative CRN is increased with no of users using OR rule. However Probability of false alarm also increases with no of users which is not desirable.

There are two approaches for which the CRN can operate on the channel [10]. In the first case, primary user is absent and no false alarm is generated by the fusion center while in the second case the primary user is present but it is not detected by the fusion center. We can represent C0 and C1 as the throughput of the CRN if they are allowed to operate in the absence and presence of the primary user, respectively. Then the average throughput of the CRN for the two approaches can be given respectively as

$$R_o(K, T_s, T_r) = \frac{(T - T_s - KT_r)}{T} P(H_0)[1 - P_{f,OR}(K, T_s]C_0 \tag{11}$$

$$R_1(K, T_s, T_r) = \frac{(T - T_s - KT_r)}{T} P(H_1[1 - P_{d,OR}(K, T_s]C_1 \tag{12}$$

Where P ($H_0$) and P ($H_1$) are probabilities that the main primary is absent and present, respectively. Hence the total average throughput of the CRN is given by

$$R(K, T_s, T_r) = R_o(K, T_s, T_r) + R_1(K, T_s, T_r) \tag{13}$$

For a fixed sensing time and reporting time, throughput depends on number of users required for cooperation.

In practice, throughput decreases with increased no of users as extra time will be wasted in reporting the decision to fusion centre. Hence by utilizing optimized no of users required for cooperation, throughput can also be optimized.

$$R_{opt} = R_o(K_{opt}, T_s, T_r) + R_1(K_{opt}, T_s, T_r) \tag{14}$$

## 4. RESULTS AND DISCUSSIONS

In this section, performance of the cooperative spectrum sensing is evaluated through analytical and simulation results using MATLAB version 12.0. The system parameters are assumed for system modeling: PU signal: QPSK with 1 MHz carrier frequency, Sampling frequency = 50 MHz, Number of samples are 1000. $P_f$ for individual user is 0.01. P ($H_0$) =0.7 and P ($H_1$) =0.3. Sensing time is 20 ms. Reporting delay is 0.1 ms, error in reporting channel q is 0.001.

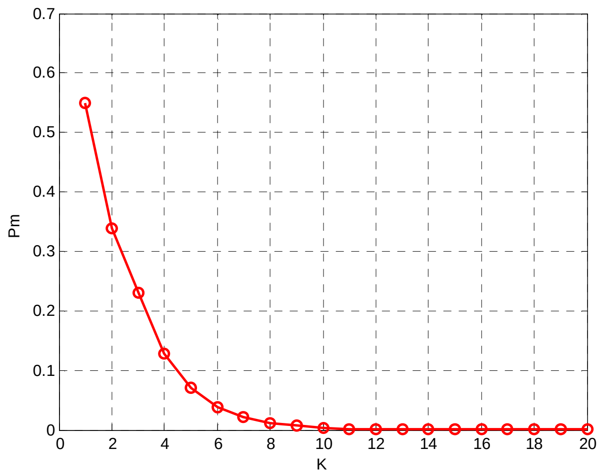


**Figure 2: Total $P_d$ of CSS Scheme with No of Cooperative Users for SNR= - 10db**

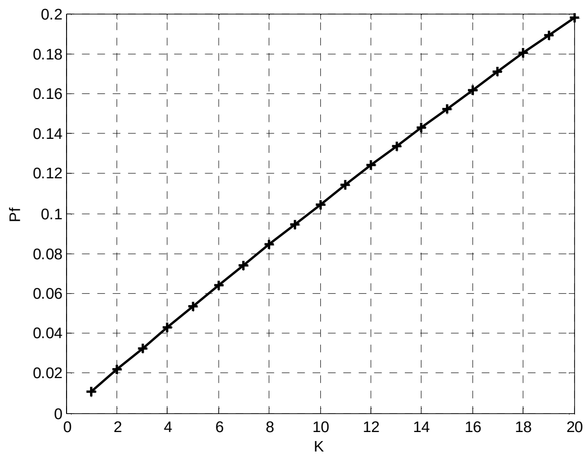


**Figure 3: Total $P_f$ of CSS with No of Cooperative Users for SNR= - 10db**

Figure 2 and 3 shows the performance of CSS in terms of $P_m$ , and $P_f$ with no of cooperative users. OR rule is used for decision fusion. It is clear from the figure that Pm decreases with increasing no of cooperative users. Low Pm reflects good performance. However, figure 3 shows that $P_f$ increases with cooperative users which is not desirable. For, SNR=-10dB, $P_m$ is 0.32 for K=2 while it is 0.05 for K= 6. Hence performance improved. $P_f$=0.02 for K=2 at SNR=-10dB while it becomes 0.062 for K=6.

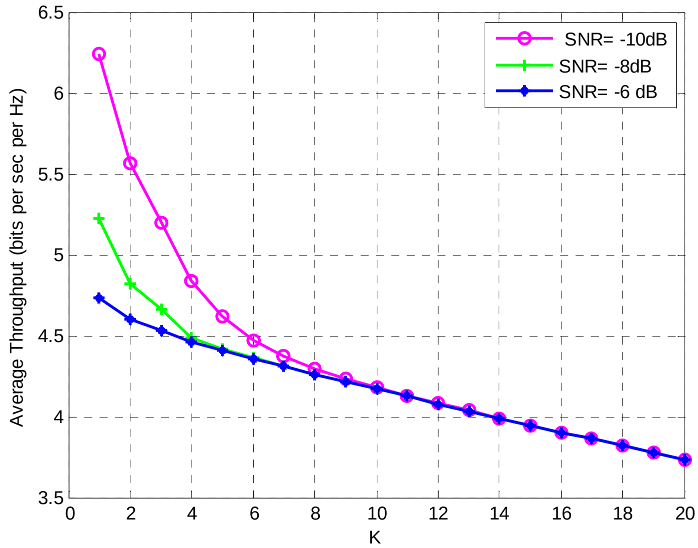


**Figure 4: Average throughput with No of User Required for Cooperation for T =20 Ms $T_R$=0.1 Ms**

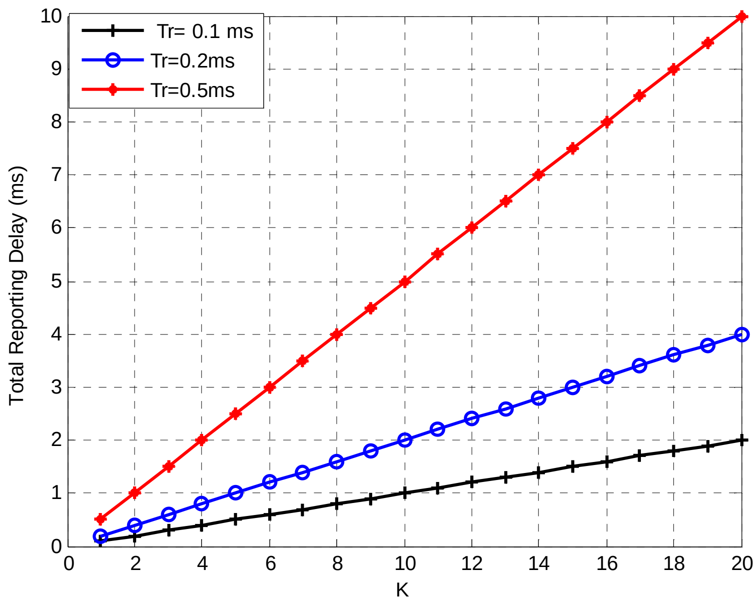


**Figure 5: Effect of K on Total Reporting Delay**

Figure 4 shows the variation of throughput with no of cooperative users. Throughput decreases with no of users. Since reporting delays increases with no of users. Moreover possibility of detecting users also increases with more no of users; hence opportunity to transmit data by secondary users decreases. Throughput at -10dB 4.8 bits per sec per Hz for 4 users while at -8 dB this throughput is approx 4.5 bits per sec per Hz. The reason for higher throughput at lower SNR is that there is very less possibility to detect PU at low SNR by ED. Hence $P_d$ is low and opportunity to avail the spectrum is high which increases throughput in turn. However if PU is present, then it may cause interference to PU.

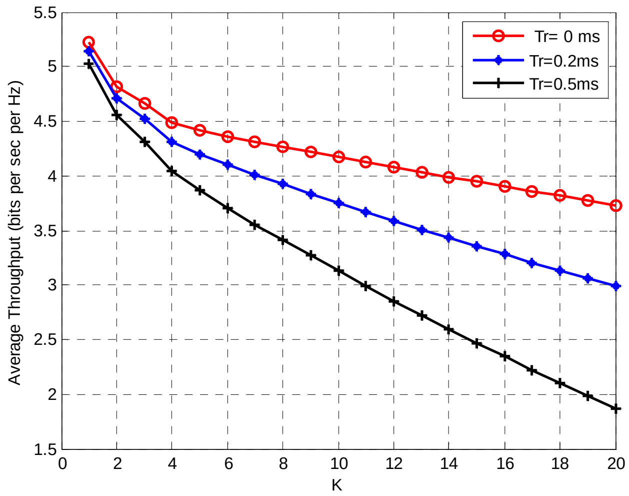


**Figure 6: Effect of Reporting Delay on Throughput**

Figure 6 shows that total reporting delay increases with number of users. For reporting delay = 0.1 ms, total reporting delay for 4 users becomes 0.4 ms. Similarly for reporting delay =0.2 ms, total reporting delay becomes 0.8ms. Increased reporting delay causes the loss of throughput. In figure 6, effect of reporting delay over throughput is shown. When $T_r$=0, throughput is decreased for higher no of users because of high false alarm probability. However when there is $T_r$ exists, it reduces the throughput further with increased number of users. When $T_r$ is high, it deteriorated the performance significantly.

## 5. CONCLUSIONS

In this paper, the performance of spectrum sensing has been investigated for Cooperative CR network. We have seen that $P_m$ decreases and $P_f$ increases with number of cooperative users for OR fusion rule. Then, effect of cooperation is analyzed over throughput. It has been found that throughput is decreased with increased no of cooperative users because of increased $P_d$ in case of $H_1$ and increased $P_f$ in case of $H_0$. Further we have investigated the effect of reporting delay on throughput of CSS. It has been found that reporting delay increases with number of cooperative users and reduces the throughput of CSS.

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